Chapter 8

Reservoir Ranching

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Global aquaculture continues to grow at a rapid rate, increasing 8.7% annually since 1970, whereas production from capture fisheries peaked in the mid-1980s (FAO 2008). Seventy six percent of global freshwater fish production is by some form of aquaculture. Reservoir ranching is a relatively new culture system contributing to inland freshwater fish production, and it is a newly defined term in this chapter to denote an extensive aquaculture practice that can provide an alternative supply of freshwater food fish under eco-friendly, minimum input, and sustainable conditions.

8.1 Reservoir ranching vs. culture-based fisheries

Reservoir ranching is an extensive culture system in which young hatchery-produced fish are stocked in existing freshwater impoundments, feed on naturally available foods, and are harvested after a period of time (Semmens & Shelton 1986; Onders *et al.* 2001). The fish may be owned by a sole proprietorship, a cooperative group, or a corporation. Private groups may gain access to reservoirs as permittees or lessees for profit or for benefit of a rural community. Reservoir ranching as a specific culture system for food fish production is part of a larger group of practices known as culture-based fisheries.

Culture-based fisheries are defined as "enhancement practices which are maintained by stocking one or more aquatic species for supplementing or sustaining

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their recruitment and raising the total production or production of selected elements of a fishery beyond a level that is sustainable through natural processes" (FAO 1997). Culture-based fisheries include enhancement measures that take the form of introduction of new and sometimes exotic species, stocking natural and man-made water bodies, supplementing with fertilizer, engineering the environment for habitat modifications and improvements, altering species composition by eliminating undesirable species and stocking only select species, and introducing genetically manipulated or modified species.

Culture-based fisheries encompass a broad spectrum of enhancement practices by stocking to increase food fish production, increase depleted stocks, provide conservation and restoration of special concern species, and supplement recreational fisheries. However, the application of culture-based fisheries depends on both the desired outcomes of the stocking entity and the attitudes of the public and government agencies. In developing countries, culture-based fisheries are primarily used to provide a low-cost protein source to rural communities and provide job opportunities. However, in developed countries, culture-based fisheries are primarily directed toward recreational fishing, or on a limited basis, enhancement of capture fisheries.

"Ranching" is a term coined in the American West to describe an extensive method of livestock production on natural forage with little input of grain-based feed. In recent years, a similarly extensive type of culture-based fishery has been demonstrated in small bodies of water (generally less than 100 ha) as a cost- and resource-effective way of increasing supplies of food fish in rural areas (De Silva *et al.* 2006). Therefore, the term "reservoir ranching" will be used in the remainder of this chapter to describe an aquaculture (farming) system that is based on continued ownership of the stocked fish, limited management input, and generation of revenue through sales of the resulting fishery products.

8.2 Reservoir

A reservoir is defined as a structure, usually man made, where water is collected and stored for future use. Reservoirs were primarily built for flood control; water supply for potable, agricultural, and industrial uses; navigation; and in some cases, generation of hydroelectric power. They have been credited with significant advancements in human development through socio-economic viability and environmental sustainability (World Commission on Dams 2000).

Reservoirs are formed from the regulated containment of streams or rivers behind structures (dams) of reinforced concrete, earth and rock fill, or a combination of materials. Reservoir dams are classified as major, large, or small. A major dam is defined as having at least one of these criteria: height of >150 m, volume >15,000,000 m^3, reservoir storage of >25 km^3, and/or electric power generation capacity >3.6 million MJ. A large dam is defined as >15 m high from foundation to crest and small dams are defined as <15 m (ICOLD 1998; Rosenberg *et al.* 2000). Since the end of World War II, global construction of large dam reservoirs has soared to over 40,000 in 140 countries. This

represents more than 10,000 km^3 of combined storage, which is about five times the volume of water in all the world's rivers (Chao 1995). China has been the leader with 24,671 dams, followed by the United States (6,375 dams) and India (4,010 dams). Various estimates exist for the total surface area of reservoirs in the world ranging from 400,000 km^2 to 1,500,000 km^2 (Shiklomanov 1993; St. Louis *et al.* 2000). Further, water impounded in reservoirs with small dams is substantial. McCully (1996), using data from USCOLD (1995) and ICOLD (1998), calculated that for every large dam there are seventeen small dams in the world. The global number of reservoirs with small dams has been estimated to be 800,000. In the United States, the US Army Corps of Engineers National Inventory of Dams, which lists large and small dams, indicated a total of 79,000 dams having about 274,000 km^2 of reservoir surface, with about 75% of the total in the small dam category.

8.3 Natural processes of reservoirs

As a culture system, a reservoir provides oxygen, regulates temperature, supplies food for fish, and processes waste entirely by natural processes. These processes are highly complex and interrelated and are beyond the scope of this chapter; however, a brief summary is offered.

Although oxygen is supplied primarily as a product of photosynthesis by algae, and to a lesser extent, vascular plants, diffusion from the atmosphere is also an important source of oxygen in reservoirs. Local weather patterns affect diffusive inputs because wind produces wave action and waves increase surface area, thereby increasing the water/air interface. Further, solubility of oxygen in water increases non-linearly with decreasing temperature. The altitude of a reservoir can affect the amount of oxygen present in the water as well. In general, solubility of oxygen will decrease with increasing altitude due to the decrease in atmospheric pressure. The seasonal patterns of water circulation or "turnover" within reservoirs are important factors in maintaining oxygen levels adequate for fish production. Reservoirs in temperate latitudes used for reservoir ranching often experience dimictic (spring and fall) turnover patterns that disrupt thermal stratification and redistribute oxygen throughout the water column. In reservoirs having high organic load with high bacterial oxidative rates, the circulation events can have negative effects on fish if mixing of the water column results in low oxygen levels.

Regulation of temperature in reservoirs is largely a function of solar radiation, and, therefore; temperature is a function of climate and weather. However, wind energy and convection are important in the distribution of heat through the water column, accounting for as much as 90% of the distribution (Wetzel 1983). In temperate region reservoirs, seasonal temperature changes gradually overcome the low thermal conductivity of water, resulting in spring and fall turnover events interspaced with the formation of thermally stratified zones through the water column.

Spring turnover in the smaller reservoirs most suited to reservoir ranching is actually a number of circulation events that take place over a short time period, perhaps only a few days, depending on weather. The lack of a thermal gradient and presence of uniform density in the cold waters of early spring present little resistance to circulation. Surface waters are warmed slightly on sunny days or similarly cooled during chilly nights, and wind provides the necessary energy for mixing. However, as warming continues and surface waters become less dense, a thermal gradient becomes established that resists circulation. Eventually, two major stratified zones are formed: the deeper hypolimnion, with temperature largely established by the water temperature at the end of spring turnover; and the warmer epilimnion, which floats on top of the higher density hypolimnion and continues to circulate. Separating these layers is a third transitional zone known as the metalimnion. A common term applied to this zone is "thermocline"; however, this term more correctly refers to the plane of greatest temperature change with increasing depth.

The thermal gradient remains in place until cooler fall air temperatures or cold rain increases surface layer density and mixing (fall turnover) occurs once more. In the interim period, oxygen typically becomes depleted in the hypolimnion, especially if light is restricted by turbidity or oxidation levels are high. As a result, fish become isolated to the epilimnion and a portion of the metalimnion. This factor must be considered when stocking rates are considered for reservoir ranching. Further, as mentioned above, low oxygen levels in the hypolimnion can result in insufficient oxygen for fish throughout the water column after the fall turnover.

The processes by which food is provided for fish in reservoir ranching and waste is recycled are so closely interrelated that they require being part of one discussion: that of food chains, which interlock to become a food web. Two food chains are easily identified in a reservoir: the grazing food chain and the detritus food chain. Both of these food chains find their origin with the primary producers, mostly phytoplankton, that synthesize new organic matter from inorganic carbon and the energy of the sun (fig. 8.1). When living, this new organic matter enters the grazing food chain, and if nonliving, enters the detritus food chain. In the grazing food chain, zooplankton consume living phytoplankton, along with the bacteria that colonize particulate matter, organic and inorganic, suspended in the water. The zooplankton is then consumed by invertebrates, such as predacious insects, and by zooplanktivorous fish. In the detritus food chain, nonliving organic matter is consumed by bacteria, which are then consumed by detritivores, such as insect larvae and mollusks, as they also consume the nonliving organic matter. In reservoir ranching, these detritivores can be an important food for benthic-feeding fish. The food chains interlock in multidirectional fashion to form the reservoir ranching food web (fig. 8.1).

The waste products of metabolism and respiration produced by ranched fish are not a consideration in the management strategy for maximum yield because the stocking densities are low. Further, water quality is not affected by reservoir ranching because the fish are not fed. However, it is worth mentioning that these waste products join normal biogeochemical cycles, including the nutrient

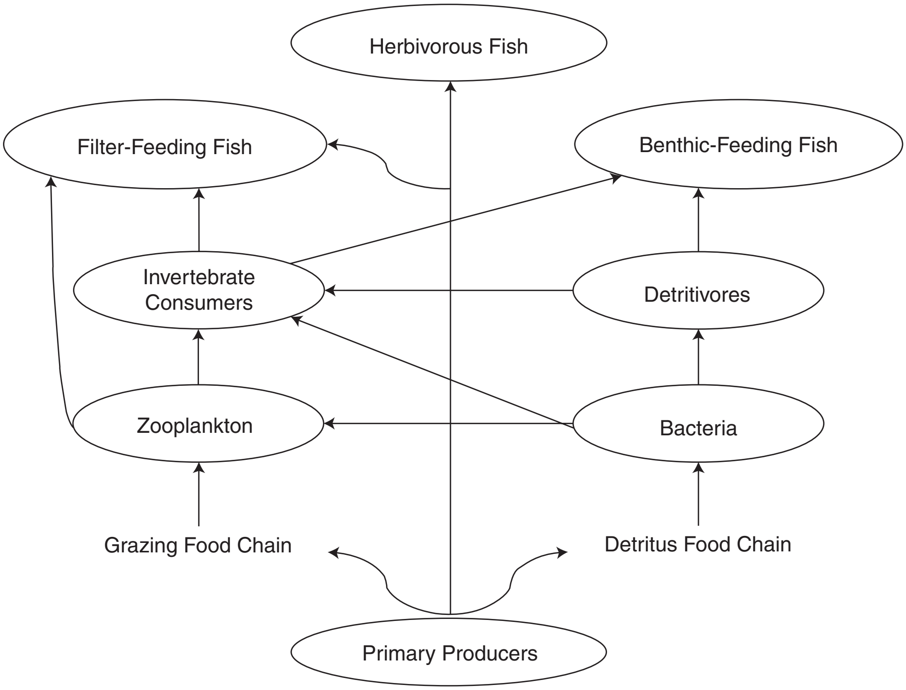

Figure 8.1 The reservoir ranching food web.

cycles that move elements and organic compounds essential to life, from the environment, to living organisms, and back to the environment. These cycles include, among others, the nitrogen, phosphorus, and carbon cycles commonly discussed in basic ecology texts.

8.4 Selection of reservoirs for reservoir ranching

There are millions of hectares of impounded water in many countries that have the potential to be used for reservoir ranching. However, not every impoundment may be suitable. Physical, physio-chemical, biological, and socio-economic factors must all be considered to determine the suitability of a reservoir for ranching of fish.

8.4.1 Physical factors

Reservoirs should store enough water to safely raise fish to market size each year. Because reservoirs often have multiple users, water consumption by the infrastructure (i.e., drinking water, irrigation, etc.) of the associated community should be estimated to ensure adequate water for the stocked fish. Also, any

historical information (i.e., age of dam and its structural integrity) should be gathered for future decision-making.

In general, most ranching has been practiced in small (<100 ha) and medium-sized (100 to 670 ha) reservoirs (Li & Xu 1995). The depth should be sufficient to prevent aquatic plant growth but not so deep as to prevent efficient use of harvest gear. Fish barriers (i.e., netting) should be in place at any outflow area of the reservoir to prevent escapement of fish or entry of unwanted fish. Reservoirs with tree stumps and other submerged obstacles should be avoided unless harvest gear and its efficiency are not compromised (i.e., seining vs. gill nets). Presence of aquatic plants can negatively affect fish production (except herbivorous species). Floating plants reduce light penetration, suppressing phytoplankton production, which is essential to primary production in the system. Aquatic plants also bind up nutrients essential for plankton growth, can provide roosts for predatory birds, and potentially hinder or prevent harvest (De Silva *et al.* 2006). Further, the reservoir should be sampled for numbers and types of predatory fishes that could prey on stocked fish or reduce their growth as a result of predatory stress. Practices such as increasing the size of stockers, increasing the number of fish stocked to compensate for losses, or reducing the number of predatory fishes should be followed, or the use of reservoirs where predators are present should be avoided. Lastly, accessibility and transportation are important considerations in reservoir selection. Obtaining and bringing in seed stock and shipment and marketing the harvested products require ready access to facilities (i.e., hatchery, end-user markets) with minimum transportation requirements (De Silva *et al.* 2006).

8.4.2 Physio-chemical and biological factors

Reservoirs have many physio-chemical and biological factors, which can cause rapid, frequent, and irregular changes in productivity so that only average rates can be determined over time (Wetzel 1983). Natural foods such as phytoplankton, zooplankton, detritus, bacteria, periphyton, benthos, and aquatic macrophytes are constantly changing in the reservoir based on environmental changes such as, but not limited to, temperature, light, nutrient inputs and recycling, generation of dissolved oxygen and carbon dioxide, as well as losses to grazing by herbivores and planktivores or foraging by omnivores and carnivores. Because fish depend completely on the natural food supply in a ranching operation, individuals compete for a finite food supply and therefore, their growth is largely dependent on population density (Lorenzen 1995).

Measurement of primary production has become the most popular way to gauge overall productivity in reservoirs and can assist in determining if the body of water is favorable for ranching. Phytoplankton abundance often has been found to have a direct correlation with fish productivity in culture-based fisheries (Lorenzen 1995; Li & Xu 1995; De Silva *et al.* 2006).

Reservoirs can be classified into four groups based on their productivity or trophic status. In increasing order of productivity, the four groups are oligotropic, mesotrophic, eutrophic, and hypereutrophic. Green, low turbidity

waters (i.e., hypereutrophic and eutrophic) normally have greater fish yields and survivals than clear or high turbidity (muddy) waters (De Silva *et al.* 2006). Though visual observation of a water body can give an initial prediction of productivity levels, a Secchi disk is a simple tool that can be used to estimate phytoplankton densities and primary productivity and has been effective in estimating fish yields. Hasan *et al.* (1999) reported that fish yield was inversely linear to Secchi disc depth in Bangladesh. Further, he demonstrated that 1.5 to 2.0 times greater fish production was achieved when Secchi disk readings were less than 100 cm, compared to readings that were more than 100 cm.

8.4.3 Socio-economic factors

Reservoir ranching requires minimal resources and less technical skills than traditional aquaculture. Therefore, lower inputs of capital are needed for start-up, and available labor can be utilized with a minimum of training. In areas with available reservoir resources, this could present an attractive management strategy for communities with minimal available capital and a local labor force in need of additional employment. Reservoir ranching is centered on water bodies that generally are communal properties or common pool property (De Silva *et al.* 2006). These water bodies often have multiple uses. Ownership of fish must be clearly identified at the planning stage so the local community is aware of this farming strategy and conflicts are avoided. Success of reservoir ranching depends on a number of important steps and factors. Initially, the producer should conduct sufficient and effective community forums to educate leadership and other multiple users of the reservoir. It is important to have suitable time for preparation of the reservoir such as installation of escape barriers and removal of unwanted fishes. The producer must identify or develop a dependable supply of seed stock at the appropriate time. Further, to utilize the local workforce the producer must train employees in the management strategy of reservoir ranching. Finally, it is essential that the producer have adequate and appropriate laws, regulations, and contracts in place to protect the enterprise and its fish and market strategies in place for the fish products.

8.5 Fish species selection

Once a water body has been selected, the type(s) of fish species can be determined. Selected species should be native, feed low on the food pyramid, accumulate biomass rapidly, and reach market size in a relatively short period of time. The species should be easily propagated and lend itself to efficient harvesting using conventional fishing gear. It should be desirable in the market place, lack the ability to reproduce in the system (i.e., monosex, hybridization, insufficient physiological-environmental cues), and be able to coexist with other selected species (i.e., polyculture) to maximize the available space and food resources (De Silva *et al.* 2006). Internationally, the species that best fit these criteria for reservoir ranching are the major Chinese carps (grass carp, *Ctenopharyngodon idella;*

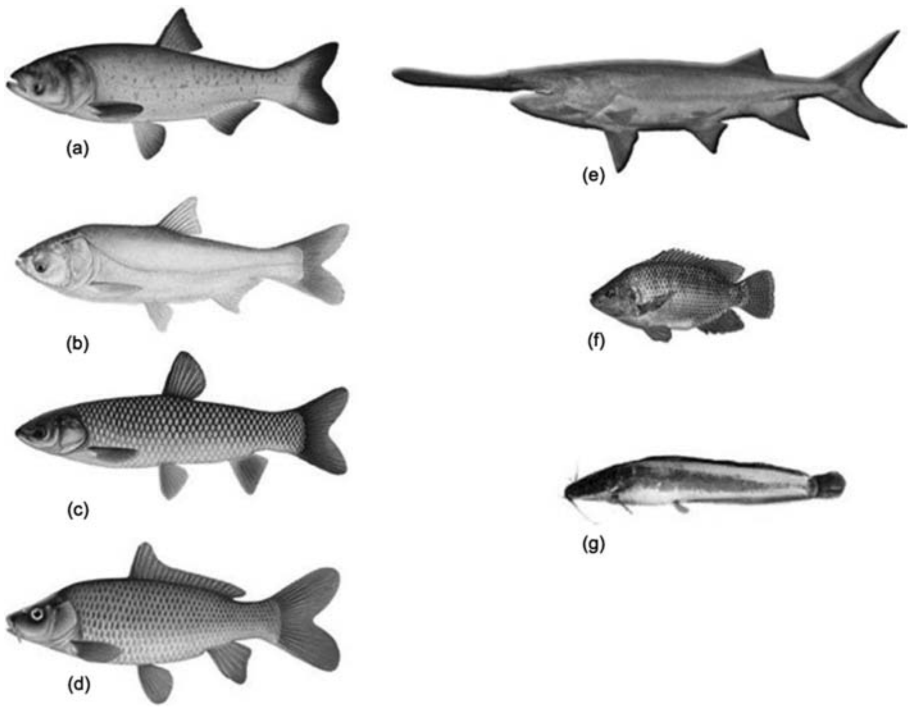

Figure 8.2 Some fish species used for reservoir ranching: (a) bighead carp (*Aristichthys nobilis*); (b) silver carp (*Hypophthalamichthys molitrix*); (c) grass carp (*Ctenopharyngodon idella*); (d) common carp, (*Cyprinus carpio*); (e) paddlefish (*Polyodon spathula*); (f) tilapia (*Oreochromis niloticus*); (g) African catfish (*Clarias gariepinus*).

bighead carp, *Aristichthys nobilis;* silver carp, *Hypophthalamichthys molitrix,* fig. 8.2; and the Indian carps including catla, *Catla catla;* mrigal, *Cirrhinus mrigal;* and rohu, *Labeo rohita*); the common carp, *Cyprinus carpio* (fig. 8.2); and the crucian carp, *Carassius carassius*. Other species are the African catfish, *Clarias gariepinus;* tilapia *Oreochromis niloticus;* and paddlefish, *Polyodon spathula* (fig. 8.2).

8.6 Stocking density and size

Stocking density should be based on the trophic status of the reservoir, desired market sizes of fish, and projected yields. Li and Xu (1995) suggested an empirical method for determining stocking density. Fast growing, fat laden fish would indicate underutilization of a food resource, suggesting a higher stocking density of individuals or all species; whereas, slow growth or presence of emaciated fish would indicate insufficient food, requiring a reduced stocking density. Stocking densities and species ratios are manipulated until optimum production of market-size fishes are reached. With over forty years of harvest data in China, Li and Xu (1995) demonstrated the use of a theoretical relationship between

stocking density (D) and fish yield (F), average harvest size (W) and return (i.e., recapture) rate (S): D = F/WS. For example, if F = 500 kg/ha, W = 0.5 kg, and S = 50%, then 2,000 fish/ha would be stocked. In addition, Lorenzen (1995) developed models for populations of carp to determine the effects of stocking densities and sizes of seed stock, which have direct application for optimizing ranching operations.

Selecting the size of seed stock is a crucial aspect of reservoir ranching. The best recapture or harvest rate is usually obtained by stocking large (>14 cm) healthy fishes that ensure faster growth, higher survival, greater yield, and better economic returns than the stocking of smaller fish (<14 cm). Chen (1982) conducted a series of experiments on stocking efficiency of various sizes of bighead carp fingerlings. The experiments demonstrated that the return rates of stocking 14.7 cm average length bighead carp were two to four times higher than rates of stocking fingerlings of average length 11.6 and 9.1 cm. Cao *et al.* (1976) found that 90% of the carp preyed on by carnivorous fish were less than 13 cm in length. Only in newly constructed reservoirs, when predatory fishes are less abundant and plankton populations are high, should smaller (3 cm) fingerlings be stocked. China currently recommends 15 to 17 cm and 25 to 30 g, respectively, as best management practices in reservoirs. Though larger fish would probably provide even higher return rates, limited fingerling production facilities and associated higher fingerling costs are constraints to this practice.

In temperate climates, fish are usually stocked in late winter or early spring. There are several advantages (Li & Xu 1995) to stocking fingerlings when water temperatures are low: Fish are less active and have less physiological stress due to handling and transport; fish predation is minimized at lower temperatures resulting in less adverse effects on newly stocked fish; and plankton populations are highest in early to late spring providing food supplies for best growth and survival of fingerlings.

8.7 Status of reservoir ranching around the world

In this section, representative countries from Asia, Africa, and North America will be used to compare and contrast reservoir ranching in different regions of the world. China has the most complete published information specific to this culture system with other Asian countries following similar methodology. Africa has little published information but it is included to emphasize the need for more impoverished countries to evaluate and invest in the use of freshwater reservoirs for food fish production. Lastly, the United States historically permitted only culture-based fisheries for recreational fishing in reservoirs but now has limited testing in small reservoirs for paddlefish as food fish.

8.7.1 China

China produces more freshwater fish than any other country in the world. Though best known for their polyculture of fish in ponds, reservoir ranching

Table 8.1 Comparison of different reservoir sizes and their trophic levels to species stock proportions, species densities, and yields using the reservoir ranching system. Table adapted from Li and Lu (1995).

		Species (% of Total)				
Size of Reservoirs (ha)	**Trophic Level**	**BH & SC**	**GC, WF, & CC**	**MC**	**Total Stocking Density (fish/ha)**	**Fish Yield (kg/ha)**
Small (<70)	Eutrophic	45	40	15	7,500	3,000
	Mesotrophic	35	30	35	5,000	1,500
	Oligotrophic	10–15	10–15	70–85	3,000	750
Medium (70–670)	Eutrophic	45	40	15	3,000	750
	Mesotrophic	50	30	20	2,300	600
	Oligotrophic	40	20	40	1,500	450
Large (670–6,670)	Eutrophic	50	35	15	1,500	450
	Mesotrophic	50	30	20	1,100	350
	Oligotrophic	40	20	40	750	225
Extra Large (>6,670)	Eutrophic	55	30	15	750	225
	Mesotrophic	55	25	20	600	185
	Oligotrophic	40	20	40	450	150

BH = bighead carp; SC = silver carp; GC = grass carp; CC = common carp; WF = bluntnose bream; and MC = mudcarp.

has provided a relatively new system that has increased freshwater fish production in the region. Though other Asian countries practice reservoir ranching (De Silva 2003), the most comprehensive information for best management practices of this system is available for China (Li & Xu 1995).

China has over 86,000 reservoirs, encompassing more than 2 million hectares of freshwater and representing about 40% of the total inland water surface area (De Silva 2003). Most of them are small (<70 ha) or medium (70 to 670 ha) in size totaling about 1.5×10^6 ha. Over 1 million tonnes of fish are annually produced in these reservoirs (De Silva 2003). Small- and medium-size reservoirs have been shown to have higher fish yields (>450 kg/ha/year) than larger size reservoirs (>670 ha; table 8.1). Li and Xu (1995) suggested that larger reservoirs have proportionally less shoreline and often less inflow of nutrients, which would result in lower fish production.

Most reservoirs in China are stocked primarily with bighead and silver carps, which account for 60 to 80% of the harvest (Li & Xu 1995). Other secondary species such as grass carp, black carp (*Mylopharyngodon piceus*), common carp, and mud carp (*Cirrhina molitorella*) are often mixed in to feed on aquatic plants and benthic organisms. Recently, mandarin fish (*Siniperca chuatsi*), a predator, have been stocked because of a greater demand by consumers and interest as a sport fish, but currently production is insignificant. Most reservoirs have their own hatchery and seed stock facilities to ensure a regular supply of fingerlings.

The fish species ratios and densities are often adjusted annually according to water fertility and the composition of food organisms (Li & Xu 1995). Bighead

carp have been found to have greater individual growth and yields than silver carp, indicating a larger food supply of zooplankton than phytoplankton. Table 8.1 provides guidelines for stocking ratios and densities to obtain a wide variety of yields in reservoirs of different trophic status.

Yields in Chinese reservoirs have improved with the increase in stocking sizes of the fish and installation of escapement barriers. Li and Xu (1995) reported that stocking a larger size fish (>14 cm) not only resulted in higher yields (i.e., up to fourfold increase in return rate) than with smaller stockers, but individual sizes were also larger at harvest. Further, escapement barriers have provided an improvement in fish yields by limiting and ideally preventing the loss of fish from the reservoir during high water events. A variety of barriers is used, such as wooden or wire fence, polyethylene/polyvinyl net, and electrified screens (Li & Xu 1995).

A variety of gear and technologies has been developed for harvesting pelagic (e.g., bighead carp) and demersal (e.g., common carp and mud carp) species from Chinese reservoirs (Li & Xu 1995; De Silva 2003). Combinations of block net, driving gear (such as air and electrical curtains), gillnets, and seines are best for pelagic species, whereas, trawling and trammel nets are best for demersal species. At least two trawling boats and four to six john-boats with thirty to forty workers are needed to harvest a medium- to large-size reservoir. Fish harvest is most efficient during the winter months when water temperature is low and the fish are lethargic and often schooled together. After harvest, fish are held in net pens in the reservoir for subsequent distribution into the marketplace.

8.7.2 African countries

Africa, with nearly 1 billion people in fifty-four different countries, is considered the world's poorest inhabited continent. Of the 175 countries reviewed in the Human Development Report (UNDP 2008), twenty-five African nations ranked lowest among the nations of the world. About 60% of African workers are employed by the agricultural sector, with about three-fifths of African farmers considered to be subsistence level. Reservoir ranching has the potential to advance in several African countries and contribute to commerce, as well as provide much needed low-cost protein to local communities.

Anderson (1989) reported that there were over 20,000 small reservoirs (<100 ha) in Africa. More than half were concentrated in Botswana, Malawi, Tanzania, Zambia, and Zimbabwe, with over 80% of these in Zimbabwe. These small reservoirs were considered to have the greatest potential for supplementing the fish supply, especially in rural areas that were long distances from large lakes where capture fisheries were well established (FAO ALCOM 1995). Small reservoirs usually have high productivity due to nutrient runoff (i.e., agriculture and sewage effluent discharge). Ownership of these reservoirs varies from private ownership for farming purposes, to community ownership for livestock water supply and irrigation, to government ownership for domestic water supply for municipalities and schools.

The fish species most often found in the small reservoirs were common carp, tilapias of the genera *Oreochromis* spp. and *Tilapia* spp., and African catfish, *Clarias gariepinus* (Marshall & Maes 1995). The Food and Agriculture Organization ALCOM (1995) developed a work plan to evaluate and implement management strategies for these reservoirs in order to better utilize these existing water resources and increase availability of food fish as well as revenue for communities. However, no information is available to determine if such plans were implemented.

Government support and/or international aid have been limited in the development of management strategies and infrastructure (i.e., private hatcheries and distribution locations) to expedite the growth of reservoir ranching in Africa. Several countries have existing small reservoirs suitable for increasing fish production but a major bottleneck is availability of seed stock. Some government-owned hatcheries can provide a limited number of seed stock, but not on the regular basis needed for proper production.

Small reservoirs were reported to have an annual mean fish yield of 329 kg/ha based on limited information collected in the 1980s and 1990s (Marshall & Maes 1995). This average yield was over three times higher than the average yield (112 kg/ha) from capture fisheries in large (1,000 to 8,000 ha) reservoirs. If these small reservoirs could be stocked and properly managed, Bellemans (1989) estimated yields of one to three million tonnes per year. Therefore, reservoir ranching should be encouraged as a production method to at least improve the nutritional status of the rural population and therefore have a positive economic impact in some countries of Africa.

8.7.3 United States

The United States has millions of hectares of surface water impounded by dams. US reservoirs were constructed for much the same reasons as elsewhere in the world: flood control, water storage, and hydropower. However, state and federal regulations and resistance from some user groups have prevented the use of reservoirs for aquaculture in any form in the United States, and recreational fishing, boating, and scenic views have taken precedence over commercial production of fish. In the United States, there is a history of commercial fishing in large reservoirs, primarily for such species as catfish, *Ictalurus* spp.; buffalo, *Ictiobus* spp.; common carp; and paddlefish. However, state agencies have gradually restricted these fisheries over several decades primarily because of the perception that they interfere with recreational fishing. This has resulted in opposition to reservoir ranching in the United States, as stocking fish for commercial harvest would be perceived as a reversal of the decline in inland capture fisheries, and this would be viewed as undesirable by recreational fishing groups and state fishery managers

In the mid-1990s, the United States Department of Agriculture (USDA) funded a pilot research project in which paddlefish were stocked in small dam reservoirs (14 to 40 ha) on private land in Kentucky and harvested after eighteen months

(Onders *et al.* 2001). Paddlefish are members of the sturgeon family and are zooplanktivores. They are valued as a source of black caviar and the meat is white and boneless (Mims *et al.* 2009). This project showed that paddlefish would survive and grow when stocked in reservoirs as Phase II (>150 g) juveniles and could be harvested with conventional gear. Subsequently, a more advanced project was proposed for large public reservoirs; however, the project was not funded at least partially due to concerns voiced by the regulatory agency responsible for management of the reservoirs.

In 2006, new regulations were issued allowing private individuals to contract with small municipalities on a profit sharing basis for ranching of paddlefish in potable water supply reservoirs (Mims *et al.* 2006). These reservoirs are owned by the municipalities; however, the management agency retains control over the fisheries. There are between 1,600 and 2,000 ha of this type of reservoir in Kentucky; however, only about two-thirds are suitable for reservoir ranching. The regulations specify that only paddlefish can be stocked and only once every ten years. Harvest gear is restricted to 127 mm bar mesh gill nets, preventing harvest of smaller fish for meat. In addition, the management agency provides no enforcement protection for the paddlefish and allows taking by archery fishing.

Despite these constraints, private individuals have contracted with municipalities and stocked over 800 ha throughout Kentucky. The reservoirs range in size from 20 to 270 ha and are stocked at up to 50 paddlefish/ha. A minimum stocking size of 150 g was selected to minimize mortality from predation. After three years, sampling has produced paddlefish up to 6 kg. Researchers at Kentucky State University are sampling two of the largest stocked reservoirs to monitor for any changes that may occur in the reservoir or sport fishery that would indicate negative effects from the paddlefish stocking. To date, no negative effects have been reported. Based on anecdotal information, one municipality has observed a reduction in blue green algae in 2008 and 2009 and has significantly reduced their cost of adding an algaecide. The paddlefish themselves are also being monitored for survival, growth, and progression to sexual maturity (≥8 years), when the females can be harvested for roe.

The results of a state-wide survey mandated by the Kentucky Legislature showed strong public support for the concept of paddlefish ranching in the state's large reservoirs (Dasgupta *et al.* 2006). Reservoir ranching of paddlefish could become an economically viable alternative to current river fisheries for wild paddlefish that are being increasingly restricted to the point of closure. Current estimates show potential revenues of US$5,000/ha, assuming 50% survival to maturity for females (harvesting 12.5 females/ha), 1.5 kg roe/harvested female, and a wholesale price of US$275/kg for caviar.

8.8 Summary

- Reservoir ranching is an extensive culture system in which young fish that feed on naturally available foods are stocked in existing freshwater impoundments and harvested after a period of time.

- Ranching provides an alternative supply of freshwater food fish for rural communities as well as in some cases for international trade under eco-friendly sustainable conditions.
- Small (<100 ha) and medium (100 to 670 ha) size reservoirs are usually best suited for ranching purposes because they generally have higher primary productivity and fish biomass per ha and are less complicated to harvest than larger reservoirs.
- Selected species should feed low on the food pyramid (i.e., plankton), grow rapidly, and be native to the region, easily propagated, harvested efficiently using conventional fishing gear, and desirable in the marketplace.
- Effective stocking densities can be determined using qualitative indicators (e.g. fast growing, fat laden fish would indicate underutilization of a food resource suggesting a higher stocking density; whereas, slow growth or presence of emaciated fish would indicate insufficient food and require stocking density reduction).
- China has the longest history of reservoir ranching using >2,000,000 ha of freshwater and producing over 1 million tonnes per year from over 86,000 small and medium-size reservoirs.
- The United States could benefit from paddlefish ranching in reservoirs by producing a regular supply of consumer-safe caviar and meat for domestic and international trade as well as relieving pressure on wild stocks, which are under strict regulations (i.e., CITES Appendix II).

8.9 References

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